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Development of a novel system for monitoring tritium in gaseous form*

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Tritium real-time measurement in glovebox or workplace is important to ensure safe operation of tritium. A novel tritium monitor system including an open-walled ionization chamber, an electrometer and an IPC (Industrial Personal Computer) has been developed to measure tritium in gaseous form. Using mesh walls, instead of sealed wall, the open-walled ionization chamber has less tritium absorption and lower memory effect. In addition, tritium gas can diffuse into the chamber's sensitive region without the assistant of sampling system and ion trap, which are installed at the front-end of commonly used flow-through ionization chambers. Background signal of this monitor system is about 3.7×10^5 Bq/m^3, and after exposed to tritium concentration at about 10^{11} Bq/m^3 for 4h, background of the monitor can recover after purging it several times with dry air. It is suitable for longtime tritium measurements in both glovebox and workplace.

Keywords: Ionization chamber, Monitor system, Tritium measurement

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I. INTRODUCTION

Tritium, an only radioactive isotopes of hydrogen and important fuel in fusion research, will be handled in large amount in fuel recycling system of ITER (International Thermonuclear Experimental Reactor) [1, 2]. Its β–rays are averaged at 5.7 keV with the maximum energy of 18.6 keV. Due to the radioactivity, tritium operation is commonly limited in confinement system, such as stainless steel tube, glovebox, and concrete walls [3]. Tritium concentration in each level of a confinement system shall be monitored to provide an early warning to tritium leakage [4].

Flow-through ionization chamber is widely used in tritium real-time measurements for its fast response and simple structure [5–7]. However, a sampling system must be used to pump gas into the sensitive region of ionization chambers [8]. This increases the risk of tritium leakage and the amount of radioactive waste. In addition, gas sample should be de-ionized by ion traps before it enters ionization chambers. Memory effect is another critical problem in the usage of flow-through ionization chambers, which may undermine the accuracy of measurements [9, 10].

In this work, a tritium monitor system with an open-walled ionization chamber was developed to meet the requirements of tritium measurements in gaseous form for both glovebox and workplace. In the measurements, tritium in gaseous form can diffuse into the sensitive region of the chamber without pumping. The structure of two mesh walls can serve to de-ionize ions ionized by tritium β-rays before it enters the sensitive region of the chamber. Memory effect is also reduced by the use of mesh wall. Ions are collected by an electrometer, and control software was developed to receive and store data from the electrometer. The design and performance of the monitor system will be specified in this article.

II. BASIC PRINCIPLES

Ionization chamber for tritium measurements is operated in saturation mode, in which all the ions ionized by β-rays emitted by tritium will be collected. In saturation mode, signal output (I_s) can be described by Eq. (1).

$$I_s = EeCV/\overline{W} + EeDs/\overline{W} + Een_{\rm out}/\overline{W}, \tag{1}$$

where, E is the average energy (eV) of β-rays emitted by tritium. e is the electron charge (C), $\overline{W}$ is the average energy (eV) to generate an ion pair in gas, C is tritium concentration (Bq/m^3) in the sensitive region of the chamber, V is the chamber volume (m^3), D is radioactive level of the chamber walls (Bq/cm^2), s is total area (cm^2) of the inner surface, and $n_{\rm out}$ is the number of ions generated outside the sensitive region.

Signal output of a chamber is contributed by tritium in the sensitive region, tritium absorbed onto the inner walls and tritium outside the sensitive region. The second term of Eq. (1) is called the memory effect. Therefore, it is necessary to minimize the influence of the second and third terms of Eq. (1) to improve performance of the monitor. So, a novel tritium monitor system based on open-walled ionization chamber was developed.

III. DESIGN OF THE MONITOR SYSTEM

A. General design

As shown schematically in Fig. 1, the monitor system consists of three parts, a detector, an electrometer, and an industrial personal computer (IPC). Signals generated in the chamber are delivered to the electrometer. A special software installed on the IPC is used for data acquisition and data-handling (conversion, display and storage).

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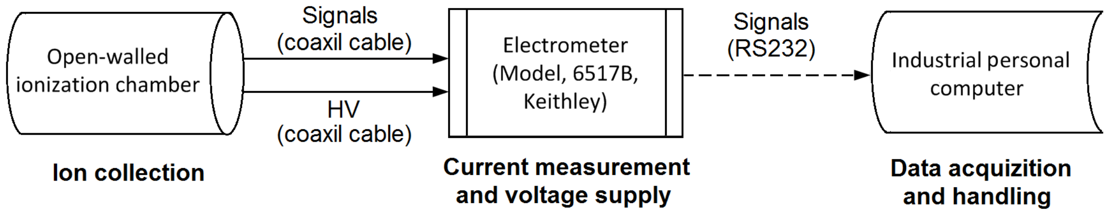

Fig. 1. Schematic design of the monitor system.

B. Specification of the ionization chamber

Instead of sealed walls of a common flow-through chambers, the open-walled ionization chamber has two mesh walls,. In measurements, the open-walled ionization chamber is placed into the glove box or workplace. Tritium gas diffuses into the sensitive region of the chamber without pumping (Fig. 2(a). With the two mesh walls, the electric field of the chamber is shown in Fig. 2(b) when a negative high voltage is applied to the cathode .The electric field between the anode and cathode serves to collect electrons in the sensitive region of the chamber—the first term of Eq. (1), while the electric field between the cathode and shield wall will prevent ions generated outside entering the sensitive region of the chamber. Therefore, the value of the third term in Eq. (1) will be zero in theory. In addition, the use of mesh wall as cathode instead of sealed wall will lead to half decrease of the surface area, which significantly lowers the influence of memory effect, as denoted by the second term of Eq. (1). As a result, with the structure of open-walled ionization chamber, the influence of both terms 2 and 3 will be diminished greatly, and the signal output of the monitor will be mainly devoted by β rays emitted by tritium within the sensitive region of the chamber.

C. The software for data processing

As described in Fig. 1, a special program was developed to receive and process data from electrometer. Its functions are: (1) receive data from electrometer, (2) convert current into tritium concentration and display it on the screen, (3) store data and make some calculations, such as summing concentrations within a period, doing average, marking maximum and minimum values etc., and (4) provide sound alarm when tritium concentration exceeds threshold.

IV. RESULTS AND DISCUSSIONS

A. The monitor system

For tritium measurements of gaseous form in workplace, the detector is placed over the equipment cabinet and is supported by a bracket. The TMS(Tritium Monitoring System)-I tritium-in-air monitor system is shown in Fig. 3. The chamber, which is 1.6 m in height (at about the nose of an adult), is installed with four wheels, being convenient to move it around. The open-walled ionization chamber can be placed into the glovebox during operation. Signals are delivered to electrometer through the cables, as shown in Fig. 1.

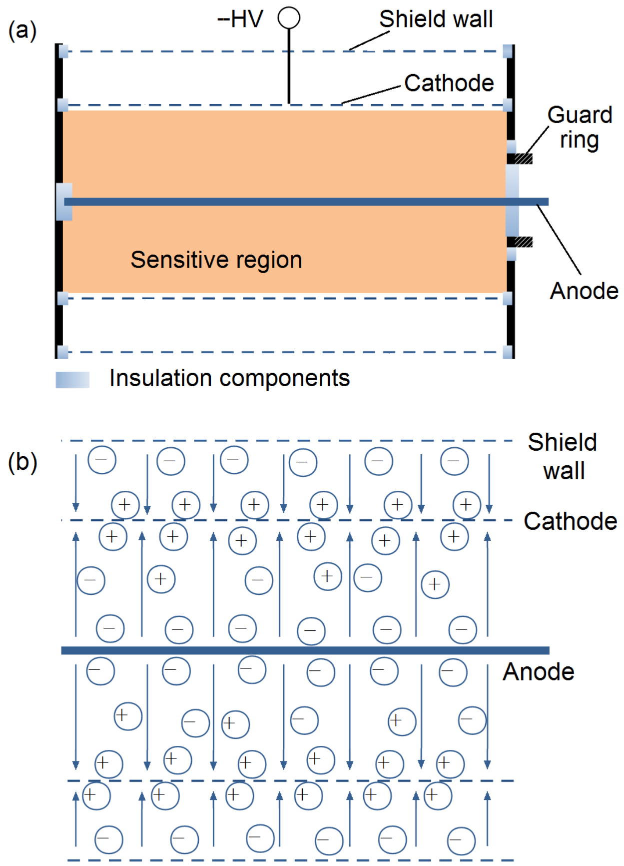

Fig. 2. (Color online) Schematics of the open-walled ionization chamber (a) and its electric field and ion distribution (b).

B. Background of the monitor

Background of the monitor was tested in laboratory. From the measurement results of about 6 h (Fig. 4), the monitor works stably. The open-walled ionization chamber is 1.0 L in volume. According to Eq. (1), neglecting the influence of terms 2 and 3, the background of this monitor system is about 3.7×10^5 Bq/m^3.

Fig. 3. (Color online) The TMS-I tritium-in-air monitor.

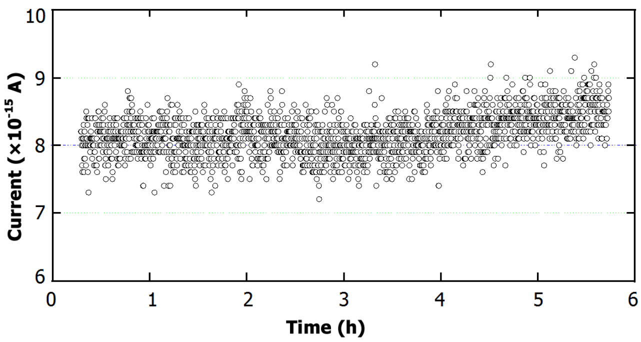

Fig. 4. Background of the monitor.

C. Saturation character of the monitor

Saturation character of the monitor system is tested at tritium concentrations of 7.0×10^9 Bq/m^3 and 6.9×10^{11} Bq/m^3. The negative cathode bias voltages vary from 0 V to 1000 V. As shown in Fig. 6, the signal output increased at first with the absolute voltage and saturated at a certain voltage. Higher voltage is necessary to ensure saturation for higher tritium concentration. This is mainly caused by ion loss due to recombination and diffusion in the chamber. For tritium concentrations of 7.0×10^9 Bq/m^3 and 6.9×10^{11} Bq/m^3, the chamber worked in saturation mode at about 100 V and 150 V, respectively. Therefore, 300 V is recommended as operation voltage to ensure the chamber working in its saturation mode.

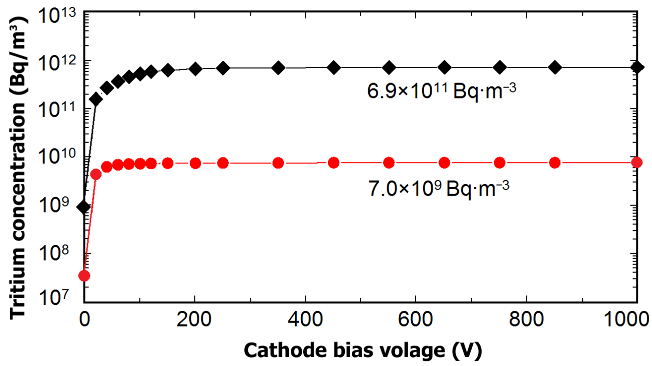

Fig. 5. (Color online) Saturation of the tritium monitor system.

D. Saturation character of the monitor

The linear response was examined by exposing the open-walled ionization chamber to a point γ-ray source placed at different distances. The dose rates varied from 0.045 mGy/h to 2.57 mGy/h, which is equivalent to 1.8×10^7–1.03×10^9 Bq/m^3. The results are shown in Fig. 6, and one sees a very good linear response of the tritium monitor.

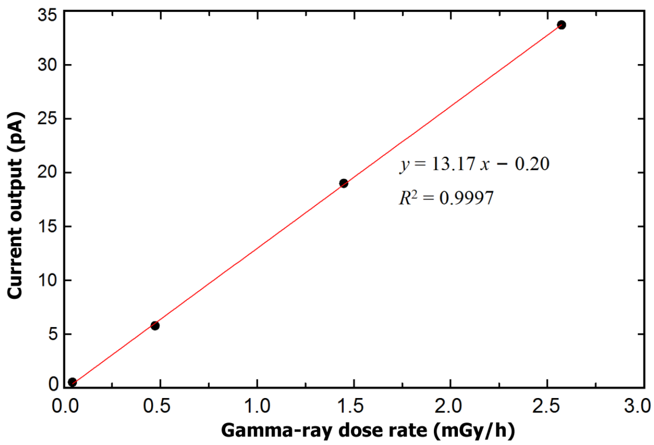

Fig. 6. (Color online) Linear response of the monitor.

E. Memory effect

Memory effect on the monitor system was checked at tritium concentration of 6.9×10^{11} Bq/m^3 in a sealed container. After putting the open-walled ionization chamber in the container for about 4 h, the tritium was pumped away and dry air was used to purge the container. Background of the monitor recovered to 3.7×10^5 Bq/m^3 in about 10 min. In comparison, background of a sealed wall chamber was higher than

1.0×10^7 Bq/m^3 after exposing it to tritium gas of the same concentration, because of the tritium adsorption on the walls.

V. CONCLUSION

A novel tritium monitor system has been developed for tritium measurements in gaseous form, especially for glovebox and workplace. The introduction of open-walled ionization chamber significantly simplifies the structure of commonly used tritium measurement system and lowers the memory effect of it. All the operations can be done on the IPC with the special designed software. With a 1.0 L ionization chamber, the background of the monitor is 3.7×10^5 Bq/m^3. It is suitable for tritium measurements in glovebox and workplace.

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